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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 5-88

UNMANNED AND MANNED EVALUATION OF A PROTOTYPE CLOSED-CIRCUIT UNDERWATER BREATHING APPARATUS, THE EX 19

LCDR M.E. KNAFELC, MC, USN

NAVY EXPERIMENTAL DIVING UNIT

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DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
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The EX 19 is an advanced self-contained closed-circuit underwater breathing apparatus (AUBA). Two prototype designs, one from S-TRON, Redwood City, CA, and the other from the Naval Coastal Systems Center (NCSC), Panama City, FL, were evaluated for their breathing performance and canister duration by unmanned and manned testing procedures. The unmanned breathing resistance results of both prototypes met the Navy Experimental Diving Unit (NEDU) performance goals established in NEDU Report 3-81. However, the negative static load of the S-TRON EX 19 made it unsafe to conduct manned testing in depths deeper than 14 feet of fresh water. In addition, the S-TRON carbon dioxide absorbent canister did not meet the specifications described in the Test and Evaluation Master Plan No. 098-10. On the other hand, the NCSC prototype met all the specifications for Milestone I of the EX 19 AUBA development.

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ABSTRACT

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KEY WORDS:

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EX 19
helium-oxygen
closed circuit underwater breathing apparatus, EX 19
breathing resistance
canister duration
advanced underwater breathing apparatus
AUBA
work
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INTRODUCTION

The EX 19 is an advanced self-contained closed-circuit underwater breathing apparatus (AUBA). Two different prototypes were designed, one by the Naval Coastal System Center (NCSC), Panama City, FL (NCSC EX 19) and the other by S-TRON, Redwood City, CA (S-TRON EX 19). The design features as described in the Test and Evaluation Master Plan No. 098-10, include electronic oxygen partial pressure (PO_2) control and a carbon dioxide absorbent canister intended to support a moderately working diver for 8 hours in temperatures of 29 to 90 °F. In addition, the breathing performance standards as published in the Navy Experimental Diving Unit (NEDU) Report 3-81 (1) must also be met.

Though each AUBA is designed to meet the same specifications they differ radically. The major differences lie in their breathing loops. The NCSC EX 19 uses two over-the-shoulder breathing bags, whereas, the S-TRON EX 19 uses two back-mounted breathing bags. In addition, to achieve the carbon dioxide absorbent canister duration in all temperatures and depths NCSC chose lithium hydroxide (LiOH) for its absorbent material. S-TRON attacked the problem by thermally protecting the canister and the breathing gas to maintain a good operating temperature for High Performance (HP) Sodasorb (W.R. Grace Co., Atlanta, GA). A detailed description of these prototypes are given in Appendix A, Human Factors Engineering Survey. This report will concentrate on the breathing loop, including breathing and canister performance of the AUBAs.

Evaluation of the prototype AUBAs breathing performance involved unmanned and manned testing procedures. Unmanned evaluations generated pressure-volume loops which represent the breathing signature of the AUBAs, including the peak inhalation and exhalation pressure, and breathing resistance. Static pressures were also measured. The combination of these factors provide an estimation of the diver's work of breathing. In addition, the carbon dioxide absorbent canister performance for a moderately working diver was determined by injecting carbon dioxide into the breathing loop. This study was performed at various temperatures and depths.

Though unmanned testing reveals pertinent information on the AUBA performance, many aspects of human respiratory physiology are poorly understood. Hence, unmanned studies can only provide a screening process to determine if the diving apparatus is capable of supporting a working diver. The acceptance of the AUBA finally rests on manned performance studies. Graded exercise measured the capability of the AUBA to sustain a diver working at moderate, moderate-heavy, and heavy loads. Though differential pressures are measured, the correlation to the diver's experience of dyspnea (air hunger) reveals how well the AUBA performs. Manned canister performance studies were not performed during this evaluation.

METHODS

UNMANNED BREATHING RESISTANCE

Unmanned testing was conducted in the Test and Evaluation Hyperbaric Facility at NEDU, Panama City, FL. The AUBA was attached to an upright mannequin and placed in a water filled plexiglass ark within a hyperbaric chamber. A breathing simulator with a piston position transducer, CO_2 add system and exhaled gas temperature/humidity controller (Reimers Consultants, Falls Church, VA) was connected to the AUBA mouthpiece. A differential pressure transducer, Validyne DP15 with a 1.25 psi diaphragm (Northridge, CA), measured the mouth pressure referenced to a location 17 cm below the mouth. This location approximated the suprasternal notch. This distance, 17.3 ± 1.5 cm, was determined by measuring 12 persons ranging in height from 154 to 188 cm and weighing between 54 and 94 kg. The unmanned test setup is illustrated in Figure 1. The testing used standardized combinations of frequency (f_b) in breaths-per-minute, tidal volume (V_T), and metabolic rates ($\dot{V}O_2$) on the breathing machine. The respiratory minute volume (RMV) is the product of V_T multiplied by f_b. All testing used a breathing simulator with a sinusoidal waveform and an inhalation/exhalation ratio of 1.0. The breathing resistance test conditions are listed in Table 1. The simulated test depths were 0, 33, 66, 99, 132, and 150 feet of sea water (FSW). Air with 100% relative humidity was used as the breathing media. Prior to conducting any study the actual volume injected by the breathing simulator was confirmed with a chain-compensated gasometer (Collins, Braintree, MA). The differential pressure transducer was calibrated to a U-type water filled manometer (Meriam Instrumentations Co., Cleveland, OH) at a ± 50 cm$\cdot H_2O$. After each study calibration checks were performed.

Breathing studies were conducted on the NCSC EX 19 with two different sets of mouthpieces and hoses. One set was from a MK 16 Mod 0 Underwater Breathing Apparatus and the other from the S-TRON EX 19. The S-TRON EX 19 was evaluated only with the S-TRON mouthpiece and hoses. However, the S-TRON AUBA used a bag within a bag design in the attempt to provide thermal insulation to the breathing gas. Because the S-TRON prototype had a stiff inner bag much smaller than the actual design specified, trials were conducted with the inner bag removed.

The AUBAs pressure volume loops were generated for each RMV and test depth. From these loops, illustrated in Figure 2, the peak inhalation and exhalation pressures, and the volume averaged pressure (area of the loop/tidal volume) were calculated.

UNMANNED CANISTER DURATION

Unmanned canister duration studies used the same setup as shown in Figure 1. Because current NEDU manned testing of canister duration uses a cycle of 6 minutes of work followed by 4 minutes of rest, unmanned testing followed the same pattern. To simulate the CO_2 production of a moderately working diver

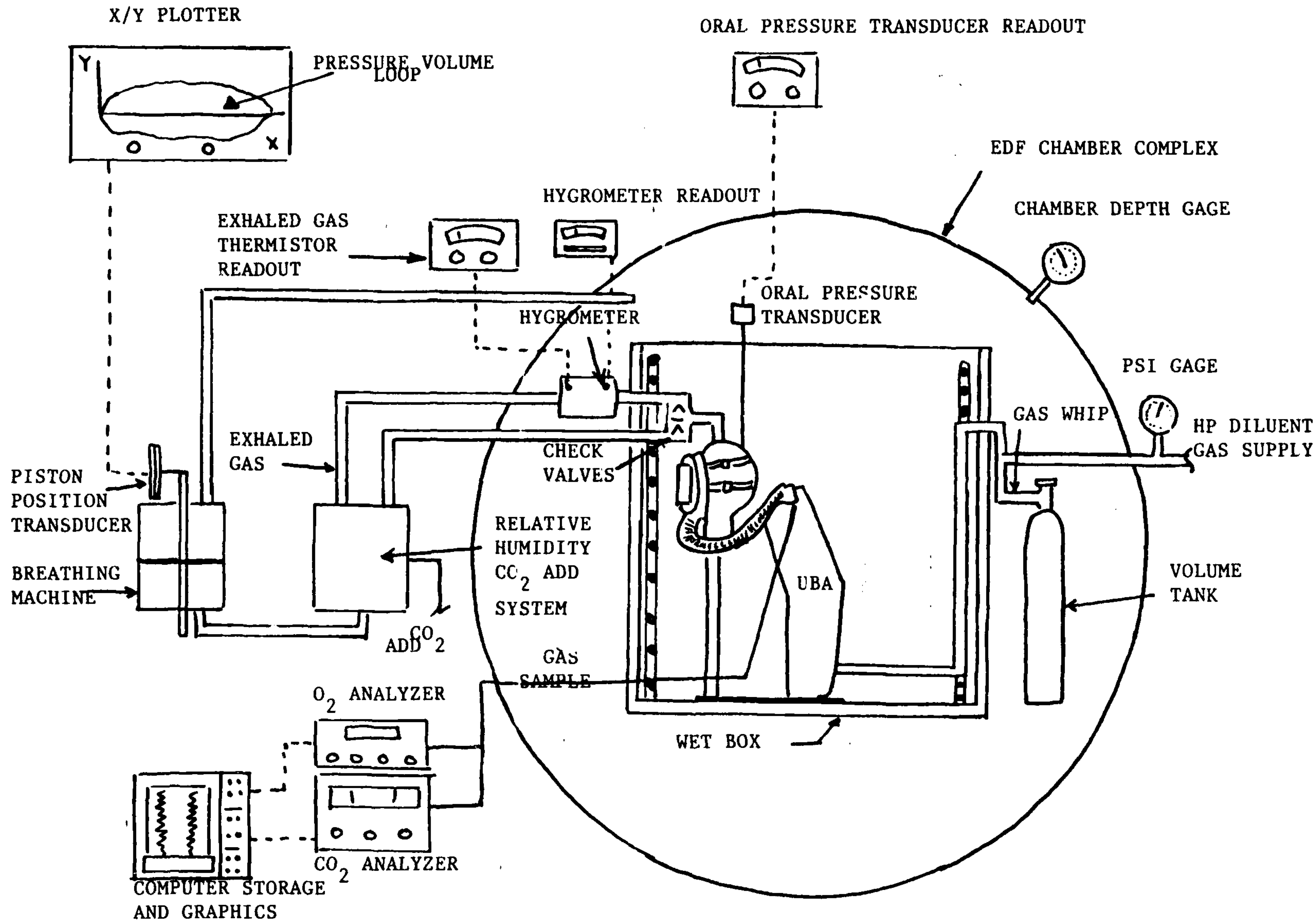


FIGURE 1 - UNMANNED TEST SETUP

TABLE 1

BREATHING RESISTANCE TEST CONDITIONS

$\dot{\alpha}_{CO_2}$ (ℓpm STPD)	RMV (ℓpm)	V_T (ℓ)	f_b	Diver Work Load
0.9	22.5	1.5	15	light
1.6	40.0	2.0	20	moderate
2.5	62.5	2.5	25	mod. heavy
3.0	75.0	2.5	30	heavy
3.6	90.0	3.0	30	extreme

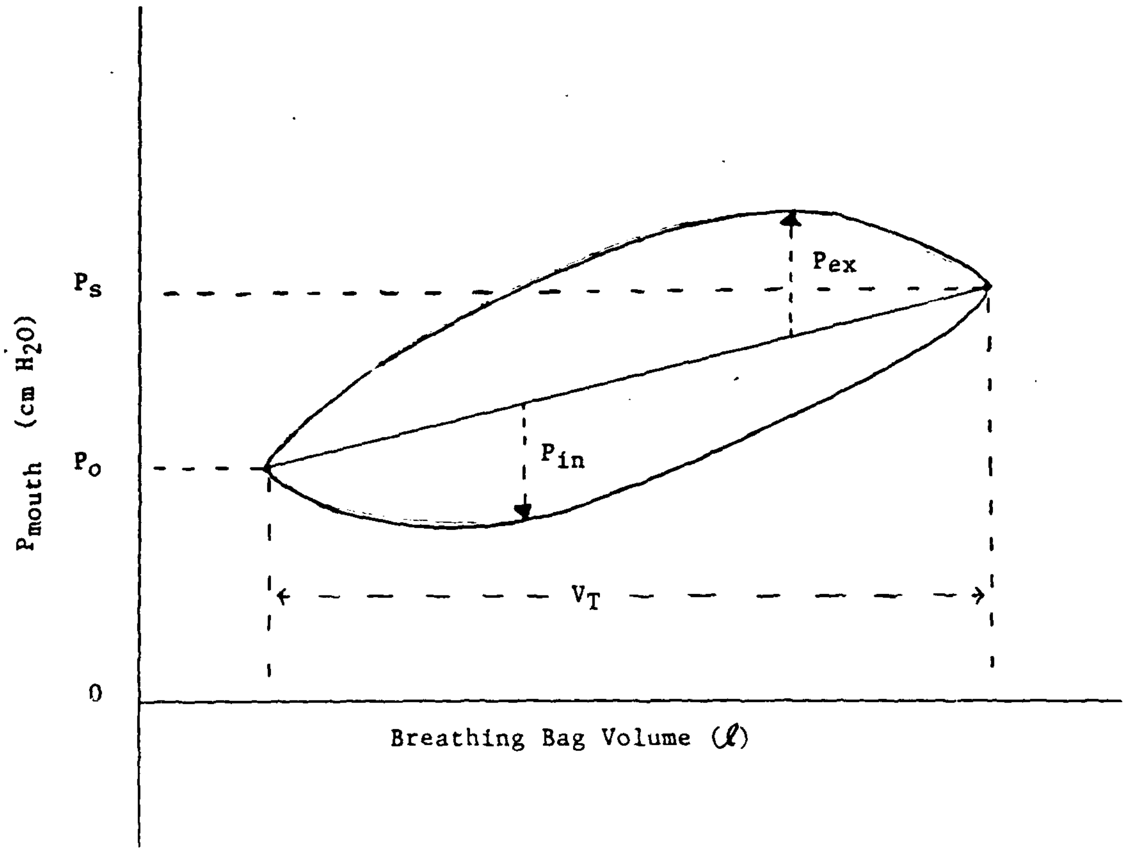
with a $\dot{V}O_2$ of 2.0 slpm STPD, CO_2 was injected at a rate of 1.8 slpm STPD. A resting diver with a $\dot{V}O_2$ of 0.9 slpm STPD was simulated by injecting 0.81 slpm STPD of CO_2. This proportion assumes a respiratory quotient of 0.9 (2). The test depths were 66 and 150 FSW in temperatures of 29 and 40 °F. A minimum of two runs per AUBA were performed at each test condition. Care was taken to insure that all breathing hoses were submerged in the water. The S-TRON EX 19 was tested using the bag within the bag as designed. Testing continued until the canister effluent CO_2 level reached 2% SEV. Breakthrough was defined as the transition area on the Time vs. Canister Effluent %SEV CO_2 curve, when the rate of the CO_2 levels in the breathing gas rapidly increased. For many canisters this typically occurs when the effluent CO_2 levels reached 0.5% SEV. This time to breakthrough was reported as the canister duration.

NCSC EX 19 CO_2 absorbent cartridges were hand packed by NCSC with National Aviation and Space Administration (NASA) grade LiOH according to NASA procedures. The cartridge contained Versapor® filters (Gelman Sciences, Ann Arbor, MI) over the gas flow openings. This design prevented water from contacting the LiOH and diffused the gas stream over the entire absorbent bed. In addition, several canister duration runs were performed using Rexsorb® soda lime (Rexnord Breathing Systems, Malvern, PA) with the same expiration date and hand packed by NCSC. The S-TRON EX 19 canister was packed by the S-TRON engineer using HP Sodasorb of the same expiration date.

UNMANNED STATIC PRESSURE

Unmanned static pressure measurements were performed on the S-TRON EX 19. This evaluation is independent of depth, therefore, the study was performed in the NEDU test pool. The NEDU standards for static loading is illustrated in figure 3. The AUBA was mounted on the test mannequin and an inclinometer was mounted to indicate its attitude. The AUBAs diluent and oxygen add systems were turned off and bled down. Using a chain-compensated gasometer gas was pulled from the AUBA through the mannequin with the AUBA in the water. Flow

PRESSURE-VOLUME LOOP
(Relative to the Suprasternal Notch)



Definitions:

P_s and P_o are the points of no flow during the respiratory cycle

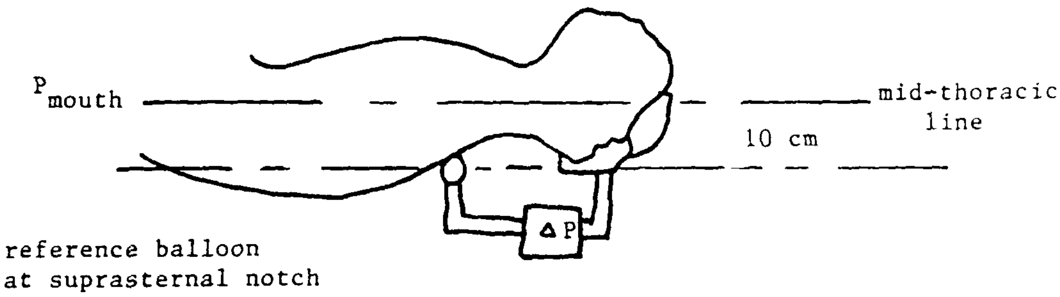
P_{ex} is the peak exhalation pressure

P_{in} is the peak inhalation pressure

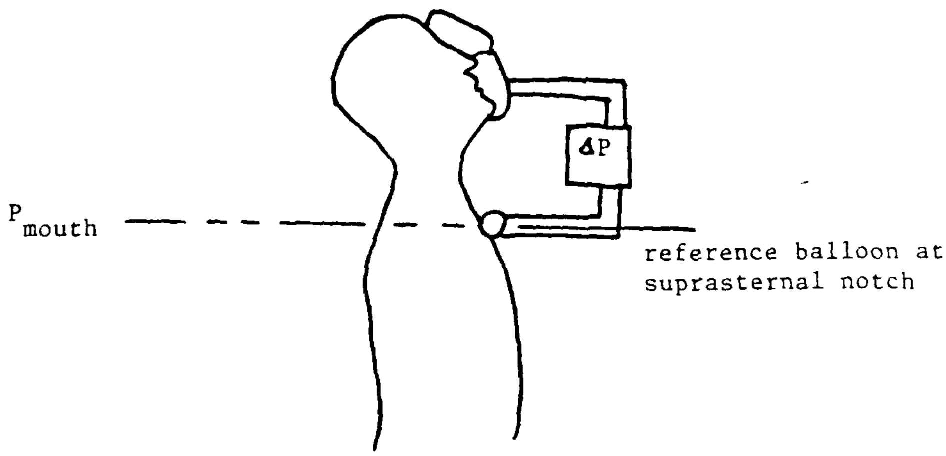
V_T is the tidal volume

FIGURE 2

STATIC LUNG LOADING



Prone



Upright

In the prone position, the no-flow mouth pressure (P_{mouth}) should be the same as the hydrostatic pressure at the mid-thoracic line. To measure the differntial pressure (ΔP) a transducer is connected to the oronasal mask with the pressure reference balloon at the suprasternal notch. It is assumed that the suprasternal notch is 10 cm below the mid-thoracic line. Thus, the pressure transducer would read +10 cm H_2O.

In the upright position, P_{mouth} should be at the same level as the suprasternal notch so that a differential pressure transducer connected between the oronasal mask and the reference balloon would read 0 cm H_2O.

FIGURE 3

was secured when the bags were collapsed as much as possible. After bringing the rig to the surface two or three liters of air were introduced into the AUBA using the gasometer. Various volumes were injected to see if the static pressure changed under the different conditions. A calibrated diff rential pressure transducer, Validyne DP9 with a .8 psi diaphragm, measured the mouth pressure referenced to the suprasternal notch on the mannequin. The measurements were recorded on a two-channel Gould strip chart recorder (Cleveland, OH). When all was readied, the S-TRON EX 19 was lowered into the test pool and rotated 360° around a transverse axis in 45° increments. The resultant static pressures were recorded as cm·H_2O relative to the suprasternal notch.

MANNED GRADED EXERCISE

Testing occurred during an Air Saturation Dive at the Ocean Simulation Facility at NEDU in February 1988. Test depths were 150, 57, and 31 FSW. Eight U.S. Navy trained male divers participated in this series. The physical characteristics of the divers are listed in Table 2. Six weeks prior to the study the divers were thoroughly trained in the testing procedures and underwent a rigorous physical training schedule emphasizing bicycle riding. During the study the divers wore a full ¼ inch neoprene wet suit in 60 to 65 °F water. Divers performed graded exercise on a tilting calibrated Collins Pedalmode ergometer (Braintree, MA) in either an upright, 45° head-up, prone or 45° head-down position. The exercise sequence included 6 minutes of work at 50, 100, and 150 watts as indicated on the controller. Four minutes of rest preceded each exercise sequence. This method allowed the diver to achieve a steady state respiratory pattern for the level of exercise (3). At

TABLE 2

DIVERS' PHYSICAL CHARACTERISTICS

Number	Height (inches)	Weight (lbs.)	FRC (ℓ)
1	72	181	4.61
2	69	195	5.91
3	73	195	6.50
4	71	154	5.20
5	68	158	5.00
6	67	163	4.90
7	70	163	5.50
8	73	216	5.34

the end of each work sequence the diver gave a dyspnea score. The definition of the dyspnea score used by NEDU is a four point scale as follows:

0 - No air hunger
1 - (Mild) A sensation of air hunger but does not impede the diver's ability to exercise.
2 - (Moderate) A very strong sensation of air hunger although not severe enough to have ever caused the diver to doubt his ability to complete the exercise period.
3 - (Severe) A sensation of air hunger sufficiently distressing to have nearly forced cessation of exercise.

The mouth peak to peak differential pressure was correlated with the diver's dyspnea score while performing various work rates in different positions and depth.

Only the NCSC EX 19 underwent manned performance testing. It was set up daily by an NCSC engineer with a freshly packed canister of LiOH and charged bottles of oxygen and diluent gas, air. An AGA (Interspiro, Branford, CT) closed-circuit full face mask (FFM) was instrumented with a differential pressure transducer, Validyne DP9 with a .8 psi diaphragm, measuring the mouth pressure referenced to the diver's suprasternal notch. Calibration using a U-type water filled manometer was done prior to the dives. Upon completion of the dives a calibration check was performed. The mouth CO_2 and O_2 levels were measured using a Perkin Elmer MGA 1100 mass spectrometer (Pomona, CA) which was calibrated prior to diving and checked between each run. A pressure transducer (Druck PTX 160/D 0-5000 psig, Newfairfield, CT) measured the oxygen bottle pressure. In addition, a data communications cable was connected to the NCSC EX 19 which allowed the surface monitoring of the AUBA electronic functions: PO_2 control, oxygen bottle pressure transducer, and the depth transducer.

RESULTS

UNMANNED BREATHING RESISTANCE

The volume averaged pressure for the S-TRON EX 19 was 0.17 kg·m/ℓ at 75 RMV at 150 FSW. The estimated peak inhalation and exhalation pressures for this condition were -8.0 cm·H_2O and +15.5 cm·H_2O, respectively. Table 3 lists the volume averaged pressures for each test condition. Figure 4 shows the S-TRON EX 19 characteristic pressure-volume (P-V) loops. The elasticity of the system is the slope of the P-V loop. It is the reciprocal of compliance and results from the breathing bags and motion of the air-water interface within the bags (4). During the last half of the inhalation phase the slope of the S-TRON EX 19 PV loop sharply increased. This pattern was seen for the majority of depths and RMVs tested.

TABLE 3

S-TRON EX 19 VOLUME AVERAGED PRESSURES
WITH S-TRON MOUTHPIECE AND HOSES

RMV (ℓ)	Volume Averaged Pressure (kg·m/ℓ)
66 FSW	
23	.03
40	.06
63	.09
75	.11
150 FSW	
23	--
40	.08
63	.13
75	.17

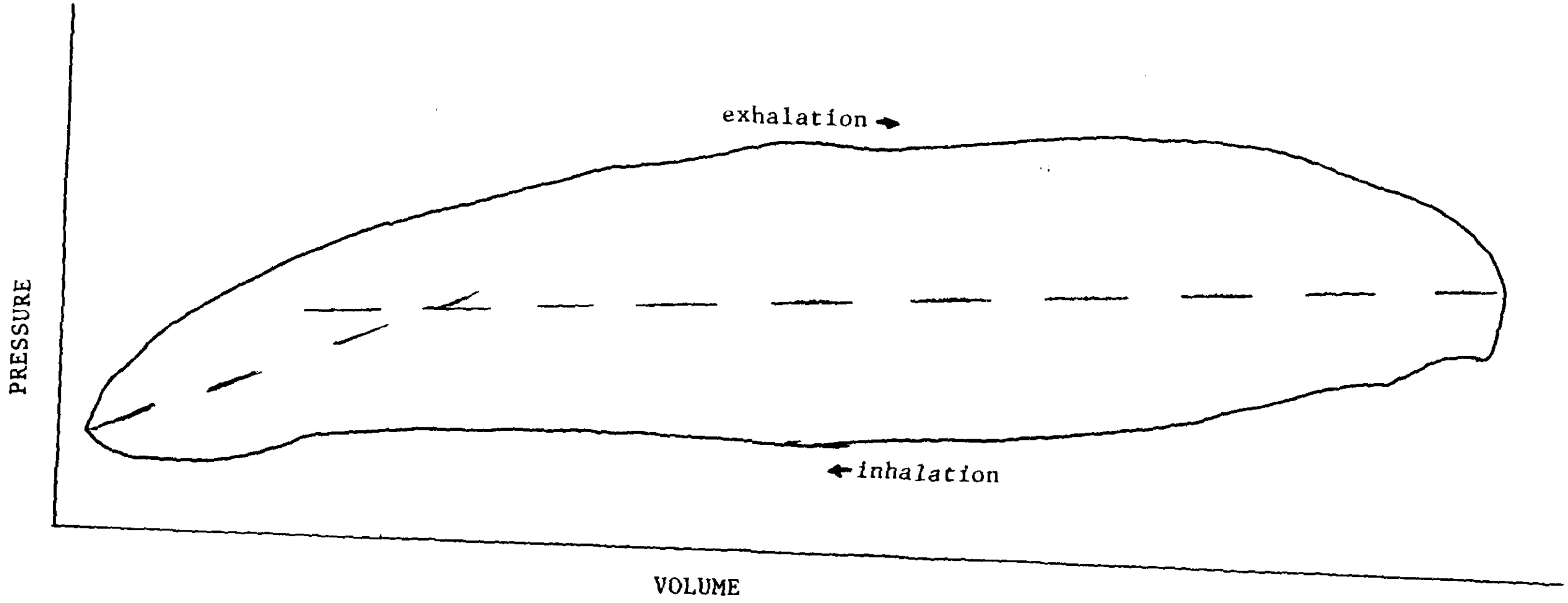
The volume averaged pressure for the NCSC EX 19 with the MK 16 mouthpiece and hoses was 0.22 kg·m/ℓ at 75 RMV at 150 FSW. When the S-TRON mouthpiece and hoses were used, the volume averaged pressure was 0.17 kg·m/ℓ for the sametest conditions. The estimated peak inhalation pressure was -9.6 cm·H_2O and the peak exhalation pressure was +12.6 cm·H_2O. The volume averaged pressures for all the NCSC EX 19 runs are listed in Table 4. Representative PV loops for the different configurations are shown in figure 5. The slope of the PV loop remained constant.

UNMANNED CANISTER DURATION

The canister duration of the S-TRON EX 19 varied with depth and temperature. There was a large drop off in performance in 29 °F at 150 FSW. The NCSC EX 19 canister performance using LiOH was not affected by depth and temperature. The results of all the canister duration studies are listed in Table 5.

UNMANNED STATIC PRESSURE

The S-TRON EX 19 has a negative static pressure in all positions except head-down, 45° head-down supine, and supine. The results of the unmanned study are in Table 6. Static pressures within the NCSC EX 19 varied with the amount of gas within the breathing loop making it difficult to fully evaluate. Overall, it appeared that the static pressure can be adjusted to a comfortable positive pressure in any position by adding diluent and regulating the exhaust relief, thereby changing the volume in the loop.



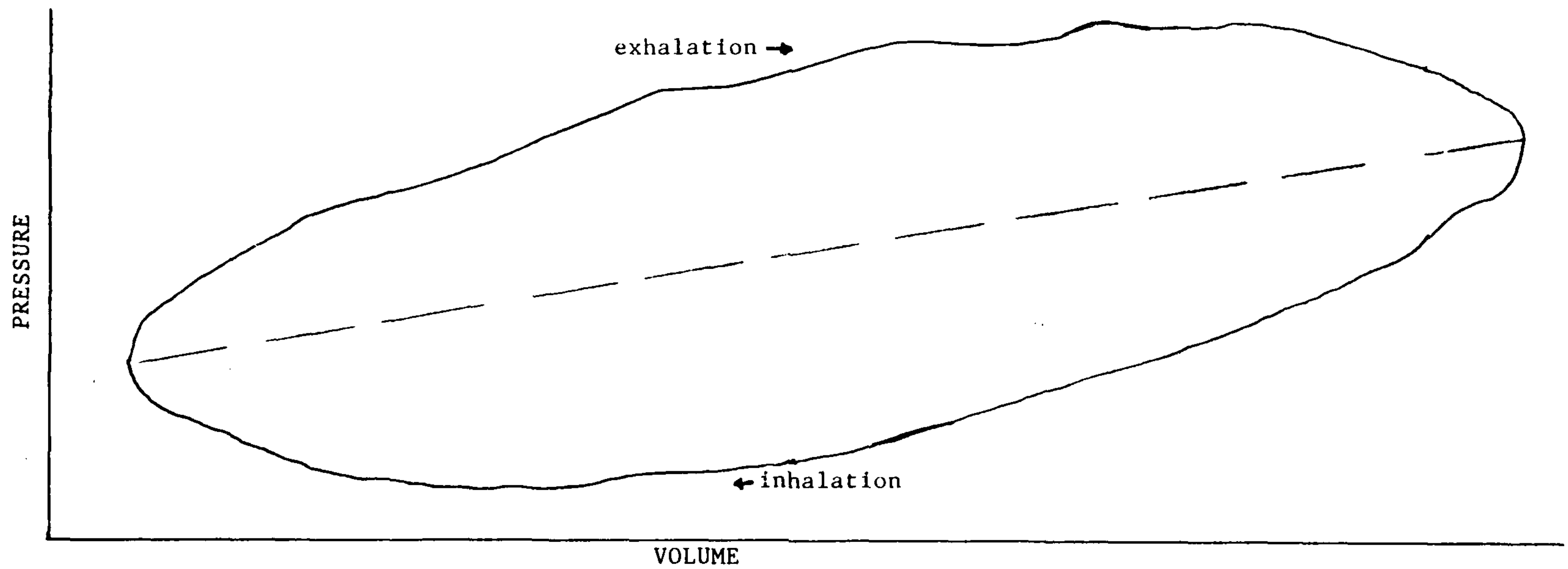
S-TRON PRESSURE VOLUME AVERAGED LOOP
150 FSW at 75 RMV

FIGURE 4

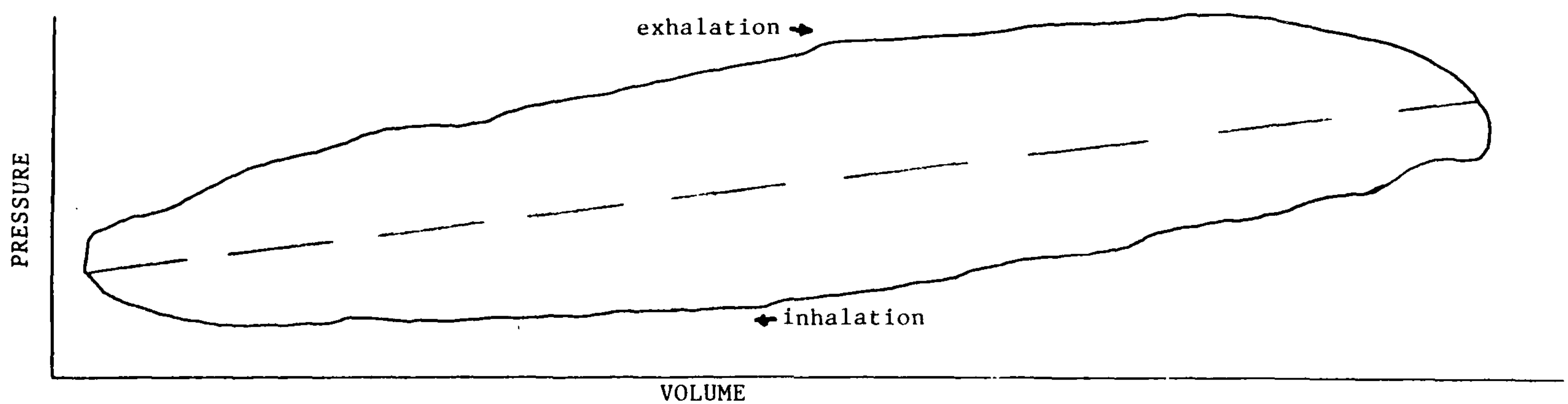
TABLE 4

NCSC EX 19 VOLUME AVERAGED PRESSURE

	MK 16 Mouthpiece and Hoses	S-TRON Mouthpiece and Hoses
	66 FSW	
RMV	kg•m/ℓ	kg•m/ℓ
23	.04	.04
40	.07	.06
63	.12	--
75	.19	.12
	150 FSW	
23	.04	.05
40	.09	.08
63	.17	--
75	.22	.17



NCSC EX 19, with MK 16 mouthpiece and hoses



NCSC EX 19, with S-TRON mouthpiece and hoses

PRESSURE VOLUME AVERAGED LOOPS
150 FSW AT 75 RMV

FIGURE 5

TABLE 5

CANISTER DURATIONS
Time in Hours: Minutes
(n = number of runs)

	NCSC (LiOH)	S-TRON (HP Sodasorb)
66 FSW		
29 °F	10:15 ± 16 (n=2)	6:19 ± 16 (n=2)
40 °F	9:35 ± 57 (n=3	6:31 ± 21 (n=3)
150 FSW		
29 °F	8:45 ± 6 (n=3)	5:32 ± 44 (n=4)
40 °F	8:49 ± 45 (n=4)	6:30 ± 23 (n=5)
	NCSC (Rexsorb)	
29 °F	2:33 ± 6 (n=2)	
40 °F	3:48 ± 51 (n=3)	

TABLE 6

S-TRON STATIC PRESSURES
(n = four runs per position)

Angle	Position	Pressure (cm·H_2O)
0°	Upright	- 14.5 ± 1.7
45°	45° Head-up	- 22.3 ± 1.9
90°	Prone	- 21.2 ± 1.8
135°	45° Head-down	- 7.3 ± 3.4
180°	Head-down	+ 7.4 ± 2.8
225°	45° Head-down Supine	+ 22.9 ± 5.1
270°	Supine	+ 24.7 ± 3.0
315°	45° Head-up Supine	- 9.4 ± 3.5
360/0°	Upright	- 15.3 ± 1.7

MANNED GRADED EXERCISE

The manned graded exercises performed with the NCSC EX 19 showed a limited correlation between the peak inhalation to peak exhalation pressures (ΔP) and the divers' dyspnea scores, Table 7. Overall regardless of depth or position, the divers were able to complete their exercise protocol with a dyspnea score of 0 or 1. One diver reported a score of 2, however, when questioned he stated he believed he was coming down with a cold. Another diver had a dyspnea score of 3 but repeated the run with a larger breathing bag volume and reported a score of 1 after completing the exercise.

TABLE 7

MANNED PHYSIOLOGICAL TESTING

NCSC EX 19 with a closed circuit AGA full face mask.

Diver	Position	50 Watts ΔP (cmH_2O)	50 Watts Dyspnea	100 Watts ΔP (cmH_2O)	100 Watts Dyspnea	150 Watts ΔP (cmH_2O)	150 Watts Dyspnea
31 FSW							
1	Upright	17.5	0	17.9	0	25.2	1
5	Upright	15.1	0	16.3	1	(a)	
2	45° Head-Up	19.3	0	20.8	1	24.2	2(b)
3	45° Head-Up	11.5	0	15.4	0	20.3	1
7	Prone	10.9	0	14.1	0	14.0	1
4	Prone	8.8	0	11.4	0	15.9	0/1
8	45° Head-Down	12.9	0	15.7	0	18.9	0
6	45° Head-Down	14.1	1	17.3	0	20.8	1
57 FSW							
8	Upright	19.5	1	19.7	0	24.6	0
3	Upright	25.4	2	20.5	2	23.7	3 (c)
3	Upright	17.6	1	16.6	1	16.0	1
1	Upright	22.0	0	20.5	0	27.0	1
7	Upright	18.9	0	20.5	0	23.8	1
5	Prone	14.3	0	13.2	0	18.2	1
5	Prone	7.2	0	10.8	0	13.3	0
2	Prone	22.2	0	24.8	0	28.1	1
1	Prone	21.1	0	19.4	1	23.8	1
4	45° Head-Up	18.9	0	21.2	0	22.5	1
6	45° Head-Up	19.7	0	19.1	1	21.8	1
8	45° Head-Down	7.9	0	10.4	0	(d)	
7	45° Head-Down	13.5	0	16.8	0	24.8	1
150 FSW							
1	Upright	27.6	0	18.2	1	22.8	1/2
8	Prone	21.3	1	24.6	0	37.1	1

(a) Diver instructed to stop before run completed for technical reasons.

(b) Diver had respiratory difficulties unrelated to the AUBA.

(c) Both breathing bags collapsed due to large tidal volume. Second run performed adjusting exhalation bag volume to remain partially inflated during inhalation.

(d) Run stopped due to ergometer failure.

Definition of Dyspnea Score:

0 - No air hunger.
1 - Mild, a sensation of air hunger but does not impede the diver's ability to exercise.
2 - Moderate, a very strong sensation of air hunger although not severe enought to ever cause the subject to doubt his ability to complete the exercise period.
3 - Severe, a sensation of air hunger sufficiently distressing to have nearly forced cessation of exercise.

ELECTRONIC FUNCTIONS

The NCSC AUBA maintained a PO_2 between 0.65 and 0.8 ATA for all work loads. The rig oxygen bottle pressure and depth gauge closely tracked the measured parameters.

DISCUSSION

The current U. S. Navy closed-circuit mixed gas UBAs do not meet NEDU performance goals of a volume averaged pressure of 0.18 kg•m/ℓ at 150 FSW and 75 RMV in air (1). The MK 15 Mod 0 with a FFM has a volume averaged pressure of 0.31 kg•m/ℓ (5). The MK 16 Mod 0 (MK 16) has a similar breathing loop as the MK 15, however, its performance is improved with large bore hoses and mouthpiece. Its volume averaged pressure is 0.26 kg•m/ℓ (6). Both AUBA designs greatly improved the breathing performance of a closed-circuit UBA. The breathing resistance within the NCSC EX 19 was minimized by its overall design which included large breathing bags (4 liter each), large bore hoses, and minimal pressure drops across the canister. The volume averaged pressure was 0.22 kg•m/ℓ. The S-TRON EX 19 also has an improved design. Of particular note were its smooth bore hoses and flapper valve design of the mouthpiece. This combination has little flow resistance and in fact when placed on the NCSC EX 19 was able to improve its breathing performance. Thus, both AUBAs meet the NEDU performance goals with a volume averaged pressure of 0.17 kg•m/ℓ.

In determining the volume averaged pressure, a pressure-volume (P-V) loop was generated. For a closed-circuit UBA it is expected that the slope of the P-V loop would be greater than zero and constant. This pattern was seen with the NCSC EX 19. On the other hand, the S-TRON AUBA had a changing slope in its P-V loop. This means the diver had to generate more pressure towards the end of inhalation to fill his tidal volume. The sensation of not getting enough gas flow for the effort partially explains the high dyspnea scores reported by the divers (7). In addition, the NEDU goal for static pressure 0 to + 10 cm•H_2O referenced to the suprasternal notch was not met. The high negative static load of the S-TRON EX 19 due to the breathing bags placed high on the diver's back further impaired the overall breathing performance and contributed to the higher dyspnea score (2, 8).

The canister duration of the NCSC EX 19 with LiOH met the performance specification for the AUBA. Furthermore, it was depth and temperature independent thus easing operational considerations when planning a mission. The performance of the S-TRON EX 19 using HP sodasorb was similar to the MK 16 despite the attempt to thermally insulate the canister and breathing gases. The S-TRON AUBA fell far short of the AUBAs design criteria.

Because of the numerous reports by divers of difficulty breathing the S-TRON EX 19 during preliminary studies in the test pool and following unmanned static pressure studies, no further manned testing was performed. Manned performance studies of the NCSC EX 19 demonstrated that a diver can do heavy work in various body attitudes to equivalent air depths (EAD) of 150

FSW. The concept of EAD is important since the gas density and hence breathing resistance is much greater at 150 FSW on air than at 1000 FSW on HeO_2. Thus, the NCSC design is readily adaptable to meet an expanded mission requirement. Due to the complexity of respiratory physiology, the correlation of the peak-to-peak pressures and dyspnea scores will be discussed in a separate report.

CONCLUSIONS

1. Due to the high negative static pressure in the S-TRON EX 19 in conjunction with its P-V loop characteristics, the S-TRON design does not meet the NEDU performance standards and seriously limits the diver's ability to do work. In addition, the S-TRON canister design does not meet the specifications in the Test and Evaluation Master Plan No. 098-10.

2. The S-TRON EX 19 did meet the NEDU performance goal for breathing resistance. An important element of their design was the low breathing resistance of the mouthpiece and hoses. Incorporation of these design features improved the breathing resistance of the NCSC EX 19.

3. The NCSC EX 19 demonstrated a sound engineering design in its breathing loop and oxygen tracking system. It met the canister durations required and NEDU performance goal for breathing resistance. The large breathing bag volume of 8 liters, 4 liters per bag, and the ease of adjusting the diluent relief valve made the NCSC EX 19 breathing characteristics adaptable to diver size, thus minimizing the possibility of overbreathing the UBA. The overall design can be adapted to an expanded mission requirement.

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APPENDIX A

HUMAN FACTORS ENGINEERING EVALUATION OF THE EX19 PROTOTYPES

S-TRON

1. DRY BENCH EVALUATION

a. Canister

(1) The canister opening is square with rounded corners and the correct position of the lid is indicated with small arrows engraved on the lid and canister which must be matched up to ensure proper closure. These arrows are difficult to locate due to their low visibility. It appears that the lid is symmetrical except for the locking grooves for the lid clamps which are on opposite sides. If this is so, then the addition of these grooves on all four sides of the lid would eliminate the need for alignment indicators. If this is not possible, the alignment indicators definitely need to be made more visible.

(2) The canister can only be reinserted into the rig in one position, but the only indication of correct placement is made by visually matching up the seal rings, which are not immediately visible from the position in which the diver would usually be standing to work on the rig. It is recommended that the canister itself contain a "This Side Up" label to make the replacement process easier and quicker to perform.

(3) The canister interior has shallow passages along each side: one side is open as part of the gas flow circuit and the other three are sealed off part way down the canister to provide an insulating dead space on three sides of the canister. Some method of shielding these spaces should be provided when loading the canister to prevent the absorbant material from spilling into and contaminating these spaces. One approach might be to integrate a shield or seal into a funnel to be used for filling the canister. A second approach would be to use a pre-packed absorbant.

(4) The interior compression segment of the canister lid is currently separate from the external seal lid. The compression springs must be carefully positioned to seat properly against the external lid. These two segments of the lid mechanism should be attached in order to simplify the loading/reloading procedure. However, the lid segments should be detachable to facilitate canister cleaning and servicing.

(5) The buckles on the tie-down straps for the canister must be positioned along the canister side or they will interfere with the fit of the canister in the backpack. At present these straps are free to slide and this positioning must be checked and corrected as the canister is installed. It is recommended that the straps be anchored so that the buckles will always be in the correct location.

(6) The latches located on the left and right sides of the canister to lock it into the backpack are operated with a lever mechanism which provides a very positive locking mechanism that pulls the seals tightly into place.

(7) The latches used on the canister lid are made of fairly thin metal and although the edges have all been rounded, the thinness of the latch does produce the effect of an edge sharp enough to be painful when pressure is applied against it.

(8) The grasping point used on the canister lid latches is short and difficult to get a firm grip on. There is a tendency to slide off the catch.

(9) The outer edge of the canister lid seal has a small tear in it and is beginning to show some wear. It is recommended that the durability of the seal be examined carefully and an evaluation made as to whether or not this type of wear will affect the integrity of the seal.

b. Gas Bottles and Regulator

(1) The hold-down strap for the gas bottles can be loosened by pulling directly out on the buckle mechanism. This might occur as the result of an impact or rough handling. An additional velcro anchor for the end of the strap is recommended to ensure that it remains secure, once fastened.

(2) Although all components are soft-mounted permitting some movement, the amount of clearance for the gas bottles is still tight enough that some flexing of the shell casing occurs when sliding the on/off valve into position so the bottle can be mounted in the backpack. The shell segment at this point is only 1/4 inch wide and has been cracked and broken, apparently as a result of this flexing. It is considered likely that this will be even more of a wear problem during routine fleet use.

(3) The on/off valve for the gas regulator is in an easily located position. The method recommended for locating the manual-add lever is to place the palm of the hand on the valve with the fingers pointing along the bottom of the shell. This places the fingertips in approximately the correct location to operate the add lever. Although this works quite well for location purposes, the possibility of accidentally turning the on/off knob during this procedure should be assessed.

(4) The on/off valve knobs for the O_2 and diluent bottles have each been given a distinctive shape. This provides an additional cue to simple positional memory and should reduce the likelihood that they might be confused during operations.

(5) The manual-add levers are currently identical in shape and can be distinguished only by location. It would be advisable to provide an

additional tactile cue to identify the O_2-add switch. This should result in an increased safety margin by reducing the possibility of confusion if the diver's functioning should become impaired.

(6) The low pressure output line projects slightly when the canister has been removed and the rig is left open during servicing or maintenance operations. This makes it vulnerable to possible impact damage under these conditions.

(7) The gas bottles are covered with an insulating substance which will prevent any bottle corrosion from being easily observed. In addition, water trapped between this covering layer and the bottles may actively promote such corrosion.

(8) Different connection fittings have been used for the O_2 and diluent bottles to prevent the bottles from being accidentally inserted into the wrong side of the rig.

(9) The O_2 and diluent bottles have a small pressure guage integrated into the valve. This permits rapid assessment of the bottles' charge status and is a useful maintenance feature.

c. Breathing Hose Connections and Mouthpiece

(1) The mouthpiece contains a one-way flow valve but flow direction is not clearly marked on the unit's exterior. It is recommended that this be done in order to simplify the reassembly process following aseptic cleaning and to reduce the risk of reversing the connection.

(2) The inhalation and exhalation connectors between the rig and the breathing hoses are not interchangeable. This was done so that if the hose-mouthpiece assembly is removed as a unit, it cannot be reattached incorrectly. It requires, however, that the inhalation and exhalation hoses (which are otherwise identical) be kept separate, since they have different connectors attached. In addition, the connector difference is an internal sizing difference which is not readily apparent from quick external observation, and this would make the separation process more difficult. It is recommended that the connectors between the two breathing hoses and the rig should be identical to simplify stocking and assembly procedures, and that a clear direction-of-flow indicator on the mouthpiece block which was suggested in item (1) be used to ensure that the breathing assembly is attached correctly to the rig.

(3) The connectors between the breathing hoses and the rig are positioned within a semicircular cut-out in the top edge of the rig. The clearance between the connector and the rig is insufficient to permit a good grip on the connector and therefore requires that an unnecessarily large number of partial turns be used to tighten it. It is recommended that the clearance be increased to decrease the time and fatigue required to perform this task.

(4) The easiest way to remove the back cover of the rig to work on the interior is to set it on its front on a flat work surface. This cannot be done without bending the hoses and putting the weight of the rig on them. This will undoubtedly result in severe wear on the hoses over time. It is recommended that the hose mountings be modified to avoid this problem and increase the ease of maintenance on the rig.

(5) The clamps currently used to secure the hoses to the mouthpiece are not easily removable for post-dive cleaning procedures. It is recommended that they be replaced by clamps which will satisfy this requirement and which are standard and available through the Navy supply system.

(6) Corrosion was noted on the inner hose connectors. Non-corrosion metals must be used at all times within the AUBA.

d. Electronics and Controls

(1) The breathing resistance for the rig can be adjusted in advance using a set screw mechanism inside the backpack. Vibration testing should be conducted to ensure that this adjustment cannot be accidentally reset.

(2) The two washers used to connect the primary display cord to the electronics housing are already showing serious rusting. They should be replaced with 316 stainless steel washers to eliminate this problem.

(3) The on/off/cal switch cannot be reached while the rig is being worn. Once turned on at the start of a mission, there is no way for the diver to turn off the rig without first removing it. Whether or not this is a concern must be evaluated by the user community within an operational context.

(4) The battery and electronics systems are completely redundant which should be an advantage for operational reliability.

(5) Currently the edge of the anchor washers which actually covers two corners of the electronics modules to lock them into position is quite narrow. It is recommended that their diameter be increased to reduce the risk that this edge might chip off under impact.

(6) The wing fasteners which are used to help anchor the battery modules into the electronics unit may be vulnerable to rotating open due to vibration. It is recommended that testing be done to determine the extent of this vulnerability and how it would affect the water integrity of the unit.

(7) Placing the male connectors on the routinely replaced items should ease the maintainability of the AUBA, since these connectors are the most vulnerable to damage. Breakage would not result in a major repair and inordinate down time.

e. Display

(1) The overall size of the unit is too large for comfortable use and needs to be reduced. The straps used to fasten the unit to the diver's forearm are not adequate to anchor the unit into position. The unit tends to shift position making it difficult to read.

(2) The integration of the independent primary and back-up displays into a single unit has the advantage of reducing the number of external hook-ups to the rig that the diver has to be concerned about.

(3) The display contains an elapsed mission time indicator which is started by pressing one of two buttons on the top of the unit. The second button turns on the backlighting and is used to acknowledge alarm conditions. These two buttons have been given slightly different shapes to aid in distinguishing between them but are located next to each in the center of the unit. It is recommended that the separation distance between these two buttons be increased to reduce the possibility of accidently depressing the wrong button. This is even more important for conditions in which gloves must be worn by the diver or his tactile sensitivity is reduced due to low temperatures. The buttons must be held down for a brief period before they will be activated. This was done to reduce the possibility that they might be activated when accidently bumped against other equipement.

(4) The display characters are black on a lighter background but appear to have adequate size and contrast to be easily read in conditions of good visibility. A multi-level color-coded backlighting is provided for low visibility conditions. The brightness level of this backlighting increases in several steps until the button is released. This backlighting then remains on for 5 seconds and will automatically turn off if not re-triggered.

(5) Alarm conditions are indicated by a flashing of the relevant piece of information on the display, the appearance of a flashing alarm report in the alarm box located at the center of the display, and the activation of a vibration alarm ("thumper") contained in the display unit. Alarm conditions which will be reported in the alarm box are low O_2 bottle pressure, O_2 sensor failure, CPU failure, and battery failure. Low diluent bottle pressure and out-of-range PPO_2 will also result in an alarm but are not reported in the alarm box. The vibration alarm can be turned off by pressing the proper button on the top of the display unit which will also turn off the flashing for the alarm box report. This report will continue to be visible and the display characters will continue to flash as long as the alarm condition exists. It is recommended that the effectiveness of the vibration alarm be evaluated in both wet and dry suits and in cold water diving situations where the diver's tactile sensitivity might be expected to be reduced. Given the relatively infrequent occurance of vibration cues in the environment, the effectiveness of this type of alarm for gaining the diver's attention as compared to more common visual or audio signals should be determined.

(6) A graphic representation of the diluent and O_2 bottles are provided on the display with appropriate labels. The level of gas remaining

in the bottles is indicated by a series of stacked black bars which recede toward the bottom of the bottle as the gas is consumed. On top of each bottle is a box containing the estimated time remaining before the bottle will be emptied. This figure is based on the current bottle pressure and assumes the current rate of consumption will be continued. Immediately below each bottle is a box containing the actual bottle pressure accurate to the nearest 10 psi.

The graphic display has the advantage of providing the diver with an immediate and easily interpreted visual report of bottle status without the need to read and interpret a digital display. The digital display provides more detailed information on the bottle pressure, however. The graphic display also uses a large amount of display space relative to a digital display. The information provided by the bottle graphics and the bottle pressure box are to some extent redundant. Given the need to reduce the size of the display unit it may be necessary to eliminate one of these indicators to save space. In that case the more specific information provided by the digital display together with its smaller space requirement should result in it being preferred over the graphics. One way to retain both might be to introduce a secondary screen level into the primary display that could be called up by the diver.

The accuracy of the estimated time remaining for the bottles needs to be evaluated carefully. It should be retained only if the information it provides proves to be reliable. Otherwise, the diver is better off with his own estimate of this parameter based on elapsed time and bottle pressure information.

(7) A clock face is located in the triangle formed by the three time parameters and is meant to act as a graphic label for these elements. This label function is not immediately clear and it is recommended that it be removed and replaced with a standard written label.

(8) In order to make the black characters readable at low light levels the display uses colored backlighting. The choice of colors does not completely conform to recommendations contained in MIL-STD-1472C. The use of black characters with backlighting, as opposed to luminous characters on a dark background usually results in an overall higher level of illumination from the display which may effect diver night vision. The provision of several levels of backlighting to permit the diver to use the minimum level needed for readability may reduce this problem somewhat. The effectiveness of these varying backlighting levels for diving at night and in turbid water needs to be evaluated.

(9) The PPO_2 indicator is a horizontal gauge with a moving triangular cursor and is located at the bottom of the display window. Due to the inset of the display below the surface of the case this can be partially obscured at some diver viewing angles. It is recommended that this indicator be moved to a more central position where this will not be a problem. The top and bottom of this gauge are labelled as "LO" and "HI" but there is no numerical labelling provided. The various sections of the gauge are appropriately color-coded in green, yellow, and red under the low light level conditions

with backlighting. Under normal lighting the sections are separated only by a black line. It is recommended that at least the top and bottom of the normal operating range be labelled on the gauge.

(10) The back-up display provides all the essential information needed by the diver if the primary display fails. The PPO_2 sensor gauges in the back-up display should be modified to match any changes made in the PPO_2 gauge in the primary display so that the same format is used for both.

f. <u>Harness and Shell</u>

(1) The straps used in the harness are 2" wide. This distributes the weight of the rig sufficiently to make it comfortable carrying the rig while topside.

(2) No crotch strap has been provided with the rig. The harness consists of two shoulder and two side straps joined at a single buckle at the center of the chest and a separate waist strap and buckle. Since there may be operational situations where the rig will tend to shift upward toward the head if not anchored in position, the addition of at least an optional crotch strap is recommended.

(3) The buckles used on the chest harness and waist straps are easy to fasten and unfasten and appear sturdy enough to withstand heavy use. There is a tendency, however, especially on the waist belt, to grip the left side of the buckle, which is rather narrow, in a manner which results in the hand being pinched when the buckle is fastened.

(4) It is difficult to readjust the shoulder straps or the waist belt once the buckles have been fastened. This may be a problem if it is necessary to adjust the fit of the rig after entry into the water.

(5) The location of the single buckle and strap attachments on the chest harness may present fit difficulties for some divers. Additional adjustment points on the center horizontal strap to which the buckle is actually fastened should eliminate this problem.

(6) The harness assembly can be removed from the rig by sliding out anchor pins (located on the inside of the backpack) which fit through loops sewn into the harness straps. The harness can easily be removed and replaced and current plans assume that each diver would trim his own harness for optimum fit and comfort and move it from rig to rig as needed. While the pins appear to be sturdy enough to stand up to operational use, they are currently not attached to the backpack in any way and could easily be dropped and lost. Also there is no place on the rig to store them when there is no harness attached and a separate storage container would be required. It is recommended that the pins be attached to the rig to avoid these problems.

(7) The lid of the rig shell is attached with four metal-reinforced pressure latches which snap back out to catch and anchor the edge of the lid.

There are two latches on each side of the rig. These latches are easy to use and appear to provide a positive lock under normal operating conditions. It is recommended that the security of this system be evaluated under impact conditions which might be experienced in some operational settings.

g. Fit

(1) When the rig is worn so that the curved outcrop at the top of the rig fits smoothly over the shoulders, the diver's head movements are restricted. This problem is particularly severe when the diver is in the prone position required by some SDV configurations. If the rig is worn lower to permit free head movement, the outcrop presses across the shoulders and becomes uncomfortable to wear.

2. IN-WATER EVALUATION

a. Fit and Comfort

(1) The flange on the mouthpiece provided with the rig was too small. The divers reported that it was necessary to really work at keeping it in your mouth. This was especially true since the hoses tended to float up, resulting in a twisting force on the mouthpiece, tending to pull it out of the mouth.

(2) The rig rides high. Head movement was restricted with divers reporting that they frequently bumped their head on the top of the rig, especially when in a swimming position.

(3) Two leg straps which were provided for the in-water evaluation was disliked by the divers and were not always used. Due to the way the rig rides, the additional restraint provided by an acceptable crotch strap should be helpful. The use of separate leg straps brought the total number of buckles to fasten to four. Several divers felt that this was too many.

b. Rig Design

(1) The rig off-gassed frequently both at depth and during ascent.

(2) The bubble diffuser was not very effective in eliminating the large air bubbles at the surface.

(3) When the PPO_2 drops, it drops fast.

c. Breathing Resistence

(1) The divers reported that this was a hard rig to breathe. Several reported feeling mild dyspnea with only minimal effort. Breathing resistence was reported to be particularly difficult in a prone position.

(2) The diluent-add system did not appear to keep up with the divers.

d. Display

(1) The readability of the current display was felt to be acceptable. Low visibility functioning of the display was not tested.

(2) The overall size of the display unit was felt to be too large.

(3) The divers generally liked the pictorial gas bottles used on the display. They felt they provided a rapid assessment of their gas status without needing to focus too closely for reading a numerical display. They felt, however, that if a trade-off was required with unit size, this type of display was nice but not essential.

(4) The cursor display for the PPO_2 received mixed reviews. Some divers felt the cursor jumped around too much and was difficult to easily locate. It was suggested that it should be moved to a more central location on the display, rather than its current position at the bottom. It was also suggested that it would be easier to read if it used a moving bar display similar to that provided for the gas bottles. The addition of some minimal scale labelling was also suggested.

(5) A blank clock face with two hands was used as a graphic label located between the time displays. This seemed to produce more confusion than help. Its label function was not immediately obvious and several divers initially expected it to serve an information function and were confused when the hands never seemed to move.

e. Low Volume Full Face Mask

Evaluation of this mask was limited due to a flaw in the prototype model available.

(1) The low volume of the mask didn't provide much space to store any water that leaked in. As soon as it entered, it was in your face.

(2) The purge mechanism for the mask required two hands to operate and several divers felt this might create problems in some situations.

NCSC

1. DRY BENCH EVALUATION

a. Canister

(1) The latches on the canister currently have a tendency to get hung up on fastenings on the canister preventing the lid from being easily removed and also tend to slip under the edge of the lid when closing. This problem is aggravated by the large number of latches required by the current canister design (3 on each side for a total of 12).

(2) Two alignment pins are located in the upper left and lower right corners of the lower canister casing. These slip through corresponding holes drilled in the upper casing to ensure that all the latches are properly aligned. They also serve to anchor the rubber canister seal in place. The durability and frequency of breakage of these pins need to be determined.

(3) The canister uses a pre-packed disposable CO_2 absorbant package which greatly simplifies the loading process. The package contains a membrane liner which is designed to eliminate the risk of a "caustic cocktail" by preventing water from reaching the absorbant.

b. Gas Bottles and Regulator

(1) The manual add switch for O_2 is located on the lower right hand side of the rig, above the on/off valve for the O_2 gas bottle. The manual add control for the diluent is contained on the breathing bag on the right hand side of the vest. This physical separation makes it extremely unlikely that the diver should confuse the two, even under conditions where his functioning may be impaired. The diluent add button may need to be increased somewhat in size to ensure easy activation when gloves are being worn.

(2) The on/off valves for the diluent and 02 bottles are located at the lower left and right corners of the rig respectively. The exact positioning and style of on/off knobs is still under consideration, although the basic location will remain unchanged

c. Breathing Hose Connections and Mouthpiece

(1) The breathing hoses between the bags and the mouthpiece are short and do not provide much range of movement. When the diver has the mouthpiece in place this may restrict his head movements somewhat. This should be evaluated during the manned in-water dives for the rig.

d. Electronics and Controls

(1) The on/off switch for the rig is located approximately half way down the rig on the left side. It is inset into the shell and should not be

easily activated by accident. No calibration switch has been included for the rig at this time.

e. Display

(1) In addition to rig status, the display is designed to serve as a decompression computer. The display contains three screen levels each of which provides four separate pieces of information. All information is displayed as digital read-outs with abbreviated labels. The primary display screen which is usually shown displays information on PPO_2, diver depth, safe ascent depth, and waiting time at present depth. The second level display contains information on diluent bottle pressure, maximum depth reached, O_2 bottle pressure, and elapsed time from start of dive. The third level display reports on predicted CO2 scrubber duration, battery voltage, water temperature, and shortest time within which the diver can safely ascend to the surface. The diver can cycle through the three display screens by pressing a toggle switch located next to the cord connecting the display to the rig. The display will automatically revert to the primary screen after 10 seconds.

(2) Rather than providing a primary and back-up display with different configurations, this rig provides two identical but independent primary displays, one mounted from each side of the rig. This has the advantage of providing the same detail and format of information on both the "primary" and "back-up" displays for the diver. It also gives the diver the option of locating the display on either his left or right arm depending on his preference or the requirements of other gear he may be carrying. It will be necessary to develop a method of storing the unused display on the rig until it is needed. This should be easily accessible to the diver wearing the rig and should not increase rig drag or risk of snagging. The left and right hand displays are currently not interchangeable due to screen orientation. If the display orientation were rotatated 90 degrees and designed to be worn on the inside of the forearm this problem would be eliminated. This would simplify both item procurement since only one display would be required and also rig set-up.

(3) The display evaluated at NEDU had black characters on a lighter background. The display face is covered by a magnifying lens which increases the perceived character size of the display. The character size appears to be acceptable. The contrast of the display, however, appears to be relatively low and may cause problems in readability underwater. This will be checked during the in-water evaluation. The angle through which the display can be read is fairly restricted. The display is constantly backlit although the level is not readily obvious in good visibility conditions. The effectiveness of this backlighting in low visibility conditions also needs to be evaluated. Some method of covering the display when lighting is not desired should be developed.

(4) The rig contains three ways in which an alarm condition is indicated. A visual alarm is connected to the rig electronics and mounted in the upper left quadrant of the diver's mask. This alarm consists of two small

red lights which are always on. If an alarm condition exists, the lights begin flashing. An audio alarm is also provided. This consists of a small disk which is connected to the rig and mounts under the mask strap immediately behind the diver's left ear. A low intermittent hum will sound if an alarm condition exists which the diver hears through bone conduction of the sound to the inner ear. Finally, the display software automatically shifts to the appropriate screen level and the relevant parameter begins flashing. The display will remain on this screen until the diver acknowledges the alarm. To acknowledge the alarm, the diver presses the screen display toggle switch. This returns the visual and audio alarm to standby and cycles the display to the next screen. The screen will then revert to the primary display after 10 seconds. If the condition causing the alarm continues to exist, the alarm will be automatically re-triggered every 10 seconds.

The use of a constant light to indicate that the rig is operating normally, provides the diver with a reassurance that the alarm system is operating. The use of a red light to indicate a "safe" condition is in conflict with the recommendations contained in MIL-STD-1472C, but may have a smaller effect on the diver's night vision than a green light would. This possible advantage should be verified before accepting this deviation from standard. The shift from a steady to a flashing light should be a sufficient status change to successfully attract the diver's attention to the alarm. The flash rate for the light should be sufficiently high that the a quick glance by the diver at the light will include at least one on-off cycle, so the light's status cannot be misjudged. The flash rate should also avoid the range which is known to produce increased risk of seizure activity in some individuals.

The ability of the diver to detect the audio alarm will vary among individuals and an appropriate sound level for this alarm needs to be determined. The relative effectiveness of a two-tone warbling alarm versus the simple on/off cycle currently used and the distance through the water that the alarm can be detected should also be evaluated.

The automatic screen switching to bring up the screen containing the parameter causing the alarm without diver action is an excellent use of software capability. It removes one possible disadvantage of having information buried on screen levels which are not normally visible. It would be better if the screen would revert directly to the primary display after an alarm is acknowledged, but this is considered a minor problem.

(5) The optimal information to be presented at each of the screen levels should be carefully evaluated, since some divers may find the process of cycling through the screens an annoyance.

(6) The automatic retriggering of the alarm after diver acknowlegement if the condition is not resolved should be eliminated. This feature is likely to lead to a tendency by the diver to ignore later alarms on the assumption that they are simply a restatement of the original alarm condition. It increases the risk that the diver will miss a second alarm condition that may arise. If an intermittent reminder to the diver that an unresolved alarm condition continues to exist is judged to be desirable by the operational community, it is recommended that a more reasonable interval than

the currently set one of 10 seconds be determined. It may be possible to develop a separate alarm pattern for such a reminder situation to further distinguish it from an initial alarm report. This possibility should be investigated if the requirement for this reminder is determined to exist.

f. Vest

(1) The current method of closing and securing the emergency flotation system inflation pockets is inadequate. It would be fairly easy to snag the flaps on something and accidentally open them exposing the air bladder to abrasion.

(2) The double zipper used to fasten the vest seems to be sturdy enough to stand up to field use, although it may be difficult to fasten if gloves are being worn. The necessity for using a double versus single zipper should be evaluated. A positive locking mechanism at the top of the closed zipper would prevent the zipper from accidentally opening during use and is recommended.

(3) The triggering pressure for the exhaust valve on the expiration gas bag can be adjusted. Currently there is no positive lock on this valve and with its placement on the front of the vest it is possible that it may scrape against something when the diver is in a swimming position and its position be changed without the diver's knowledge.

(4) The water drains located at the bottom of the breathing bags require both hands to operate and may present difficulties for divers' wearing gloves.

2. IN-WATER EVALUATION

a. Fit and Comfort

(1) Two different hoses were used during these evaluations. The first set of hoses were felt to be too long and tended to float up, creating drag on the diver while swimming. One diver also noted some minor restriction of head movement when the long hoses came into contact with the full breathing bags. A shortened set of hoses were provided for later dives. These proved to be too short, resulting in greater restriction of head movement. More work needs to be done on this, to determine an optimum hose length for use with this rig.

(2) Several divers commented on the fact that despite their initial expectations, the breathing bags in the vest did not prove to be an obstacle. In addition to swimming, the divers also used a Mk8 SDV to evaluate ease of entry and exit and comfort while in a seated position within the boat. One diver reported that he felt the bags gave some minimal interference with head movement, rating the pull experienced as about 2-3 on a scale of 10.

(3) Divers involved in the evaluation varied considerably in size but the adjustments provided for the vest were adequate for all.

(4) Generally the divers found the rig to be comfortable both in seated and swimming positions.

b. Rig Design

(1) The diluent-add system was successful in keeping up during a rapid descent and the diver were not able to deflate the breathing bag.

(2) No off-gassing was noted during change of attitudes (head up, head down, side rolls : left and right side up). A slow ascent to surface in a normal position also did not appear to produce off-gassing. If the diver ascended while on his back, the rig did off-gas when he then rolled to the left.

(3) In its current configuration, the weight of the backpack when rolling can produce enough torque to force a complete roll.

(4) Several divers voiced concern that some of the controls and valves on the vest would be extremely difficult to operate successfully if they were required to wear gloves.

c. Breathing Resistence

(1) In general, breathing resistence on this rig was evaluated favorably in all attitudes with positive comments from the divers outnumbering negative comments by about four to one. Resistence was reported to be higher when the diver was positioned on his back and when the diver was ascending with full bags.

d. Display

(1) Even in the good visibility conditions of the NEDU test pool, the display characters could not be seen well underwater. The angle through which the display could be read was also rather limited.

(2) The wire connecting the wrist display to the rig was felt to be too long and appeared to be a possible snag hazard. In addition, with separate wires for the visual alarm, the audio alarm and the two wrist displays, it was felt by several of the divers that there was too much clutter from the rig.

(3) The presence and position of the constant red light face mask alarm indicator was commented upon favorably by several of the divers. It was felt to be out of main sight but still noticeable. The fact that even after the diver acknowledged the initial alarm, it would continue to go off every 10 seconds if the underlying problem was not eliminated proved to be extremely annoying to several of the divers.

(4) The audio alarm received mixed reviews from the divers. Some divers liked it and felt that it provided a good back-up alarm. Some felt that it would not be suffiently noticeable over the SDV boat noises and others voiced concern over how far the sound could be detected through the water.

e. <u>AGA Full Face Mask</u>

(1) The mask provided with the rig leaked when near the surface. There was some minimal pop-off when turning on left side, but overall no pop-off in any attitude. There was no positive pressure in the mask but it was difficult to stop the leaking which occurred when ascending the ladder from the bottom of the NEDU test pool. The only way to stop the leaking was to hold the mask against the face. When this was done, there was minimal to no off-gassing. Breathing was judged to be good in all positions.

f. <u>Vest</u>

(1) The original 60 pound lift floatation device which was integrated into the vest did an excellent job in positioning the diver on the surface with his face out of the water. The diver was immediately righted when he relaxed after attempting to force a face-down position. The floatation bags have since been scaled down to 20 pounds and this version has not yet been evaluated.

(2) The divers gave very mixed reviews to having the floatation gear integrated into the rig vest. These views were heavily influenced by the background out of which they worked and revolved around whether the rig was considered to be ditchable or not and how likely such an emergency was to develop. Those who considered the rig to be ditchable felt that an alternative floatation system was essential.

(3) The integration of the weight belt into the vest received more uniformly positive reviews. It was felt that this method of carrying the weight resulted in better weight distribution and balance and resulted in a more comfortable system to dive. The need to be able to drop the weights easily if required was strongly emphasized, however. Some divers felt that the weight pockets as currently configured might prove insufficient for some diving situations. They felt that additional weights might be needed for use with wet and dry suits.

<u>GENERAL ISSUES</u>

1. Many of the differences in opinion which occurred among the divers evaluating the rigs were clearly attributable to the diving community from which they came. A single rig which all user groups will be completely happy with will be difficult to achieve.

2. The importance of ensuring that the rig will be fully compatible with other items of diving gear was repeatedly stressed by the divers involved in the evaluation of the two rigs. This included such items as wet suits, dry suits, floatation gear, weight belts, and gloves. Recommended items for use with the rig should be identified so that compatibility tests can be performed.